SOME FEATURES OF THE CIRCULATION AT THE 10-MB. SURFACE JULY 1958 THROUGH JUNE 1959

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ABSTRACT

A recently published set of 10-mb. charts, analyzed six times monthly, is used as a basis for the discussion of circulation and temperature patterns during the year from July 1958 through June 1959. Comparison with events that transpired at that level throughout the previous year is made, and the most pronounced differences are investigated.

The transition of the extremely stable summertime easterlies to the more intense wintertime circulation of predominantly westerlies is found to be orderly and closely related to radiation cooling in northern latitudes. In contrast, the timing of the highly complex springtime reversal can vary considerably from year to year, appearing to be influenced by the timing of wintertime developments such as "explosive warmings" and accompanying circulation changes.

During the winter of 1959, data coverage over the Caribbean area was sufficient to allow delineation of low-latitude disturbances. A 10-mb. shear line system, moving northward through the area during January, is briefly discussed.

1. INTRODUCTION

Within the past few years increasing emphasis has been placed on mid-stratospheric [2] research in an effort to determine the character of the circulation of this layer. Only since the beginning of the IGY in July 1957 have sufficient observations become available to depict synoptically these high-level circulations over a portion of the Northern Hemisphere. Previously, most studies involving the mid-stratosphere were limited to discussions of short-term circulation and temperature changes because of the lack of a series of reference charts, such as those available for tropospheric levels.

One of the functions of the Stratospheric Meteorology Research Project of the U.S. Weather Bureau has been the production of a 3-year series of 10-mb. (approximately 31 km.) constant pressure charts. Among the early publications of the Project was a booklet containing three-times-monthly 10-mb. charts for the period from July 1957 through June 1958 [9] and a discussion of the circulation for that period [8]. A more recent booklet of 10-mb. charts, covering the time period from July 1958 through June 1959 [10], includes six charts monthly for all but the summer months, and an analysis encompassing a larger area than the previous booklet. Some features of the 10-mb. circulation during this more recent period, and a comparison of circulation and temperature patterns with those of the previous year are discussed in this paper.

2. DATA PROCESSING AND ANALYSIS

The problems involved in the processing and analysis of 10-mb. data are numerous and have been discussed previously in great detail [8]. Several of these problems were alleviated by the experience gained from earlier analysis and the pronounced increase of observed on-level data. The reduction of the time interval between charts was also helpful in allowing more precise tracking of rapidly moving systems during periods of unusual stratospheric activity.

The main problem encountered in this type of analysis continues to be the erratic variation of reported temperatures and heights that is evident even after the application of corrections for the apparent diurnal variation caused by solar heating of the instrument [6]. This random variation is especially troublesome in the analysis of charts for the summer months, when the temperature varies by only 10° to 15° C. from the North Pole to the Tropics. The corrected temperatures at a given station may fluctuate in an unreasonable manner as much as 6° to 8° C. from one observation to the next. This situation forces a smoothing of the isotherms in order to achieve conformance with the wave number, amplitude, and phase of the contour field.

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[2] The term mid-stratosphere as used in this article is defined as the 10-mb. constant pressure surface (approximately 31 km.) and immediately adjacent layers.

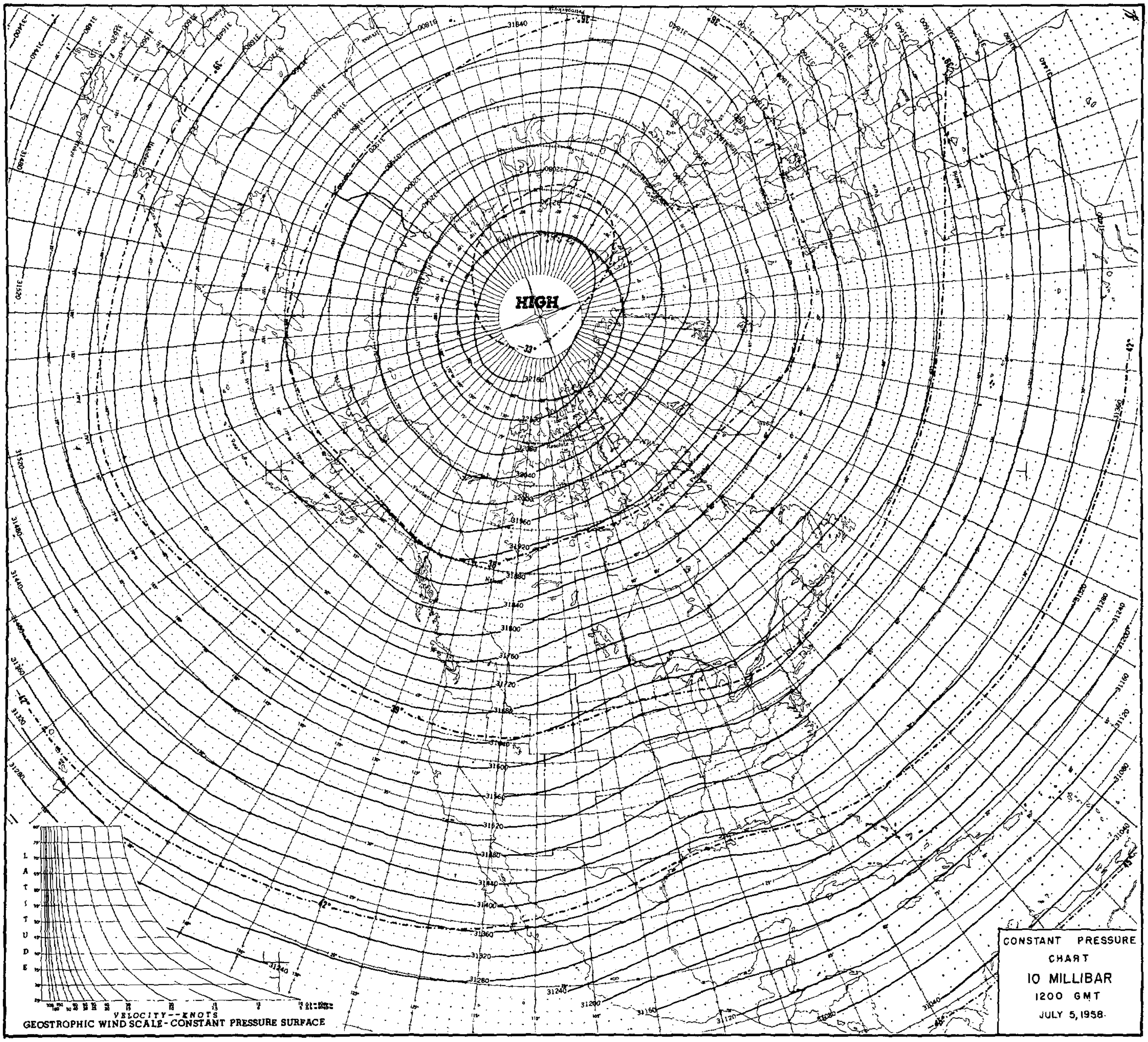

FIGURE 1.—10-mb. chart for 1200 GMT July 5, 1958 (from [10]). Contours at intervals of 40 m.; isotherms (dot-dash lines) at intervals of 3° C.

Day to day consistency of wind data appears relatively good when compared with that of reported temperatures and heights. Therefore, the winds were given most weight in determining the contour analysis, with the reported heights being employed primarily to determine the numerical values used in labeling the contours.

3. THE ANTICYCLONE OF THE SUMMER MONTHS

The summertime circulation of the mid-stratosphere over the Northern Hemisphere is characterized by a warm, circumpolar anticyclone with easterly winds at nearly all latitudes. During the 1958 summer this pattern was well established by the middle of June and persisted until late August. The 10-mb. chart for July 5 (fig. 1) [3] is representative of the midsummer pattern and shows this anticyclone near peak intensity.

The summer charts tended to verify the existence of small-scale perturbations in the mean flow, suggested by Teweles et al. [8]. In most cases, the wind direction

[3] Figures 1, 3, 5, 6, 8, 12, and 14 are reproduced, after reduction to approximately one-half size, from U.S. Weather Bureau publications [9, 10]. In the reduction process the plotted data became illegible and were removed from the charts. Institutions or research groups having need for greater detail than is found here will be furnished with a copy of the publications, as long as the supply lasts, upon request to Chief, U.S. Weather Bureau, Reference A-3.1, Washington 25, D.C.

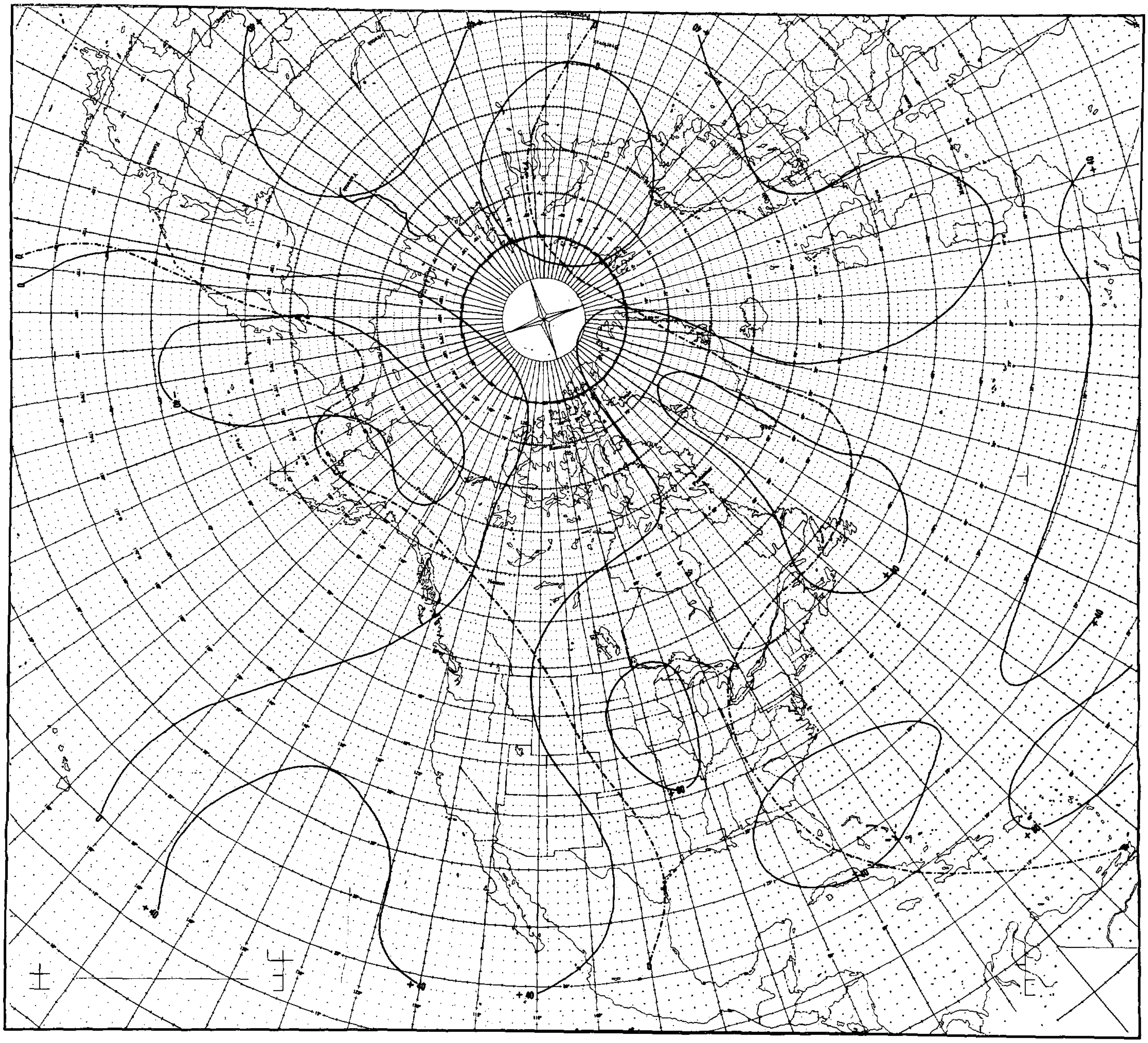

FIGURE 2.—10-mb. height and temperature change chart, July 15, 1958 minus July 5, 1958. Isallohypses at intervals of 40 m.; isallotherms (dot-dash lines) at intervals of 3° C.

deviated from easterly by only 10° to 30°. There was strong evidence that these perturbations existed at nearly all latitudes, although their amplitude, wavelength, and movement were difficult to ascertain.

The remarkably stable summertime pattern once established changed little during a short time interval as can be seen from the 10-day height change chart for the period from July 5 to 15, 1958 (fig. 2). Maximum height variations amounted to only ± 80 m., with associated temperature changes of less than ± 3° C. The distribution of the small isallohypsic centers illustrates the influence of small-amplitude perturbations in the mean easterly flow. A comparison of the July 5, 1958 chart with that for the same date in 1957 reveals the uniformity of the anticyclone from year to year. Anticyclone center values for both years were identical and approximately equivalent contour gradients were evident at all latitudes. The net annual height and temperature difference between the two charts is no larger than the 10-day change.

4. BREAKDOWN OF THE SUMMER EASTERLIES

With the steady decrease in solar insolation over northern latitudes during late summer, the anticyclone weakened considerably and by August 25 (fig. 3) had moved away from the vicinity of the Pole and split into two cells. The major cell was centered over western

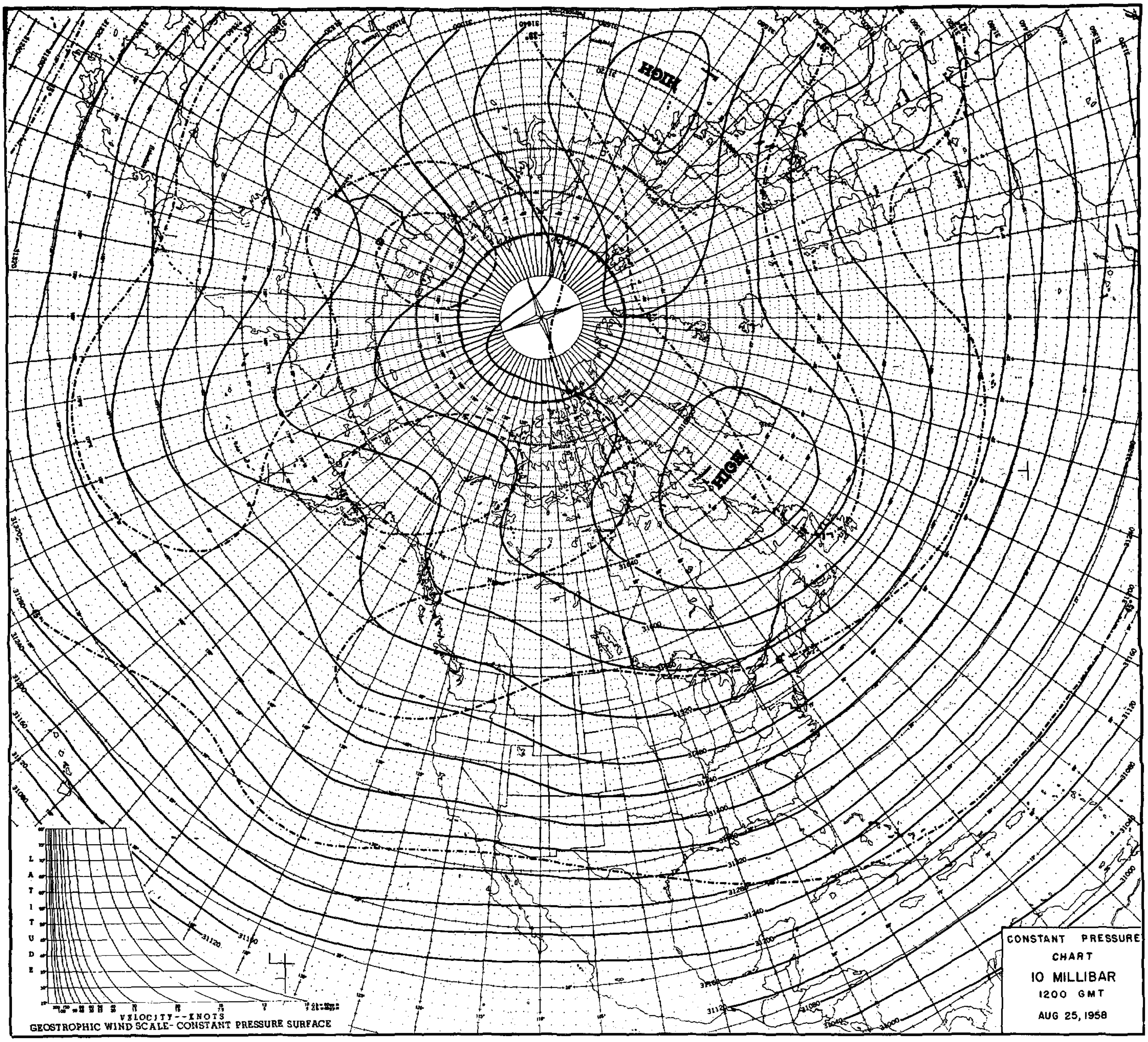

FIGURE 3.—10-mb. chart for 1200 GMT August 25, 1958 (from [10]). Contours and isotherms as in figure 1.

Russia while a weaker one was positioned over the Labrador Sea. Simultaneous with the southward movement of the anticyclone, the contour gradient over the opposite side of the Pole weakened and was accompanied by an amplification of the perturbations in the mean easterly flow. The easterly flow was especially disturbed over a broad area extending from central Canada westward into Siberia.

During the last days of August, a closed Low formed over the Arctic Ocean. As this vortex deepened and migrated to a position near the Pole, the remnants of the polar High progressed farther southward to merge with the continuous belt of mid-latitude ridges located between the still strong easterlies in low latitudes and the lighter, more variable westerlies to the north. The low center, once established, became a dominant feature of the circulation pattern. The 10-mb. surface descended quite rapidly in the northern latitudes, and after September 10 the lowest heights were no longer in the equatorial region.

During a 26-day period from August 15 through September 10, the height decrease at the Pole amounted to approximately 760 m. (fig. 4) with the gradient of the height change appearing remarkably uniform throughout the high and middle latitudes. This symmetry must, in great measure, be a consequence of radiational cooling, even though other aspects of the breakdown, such as the formation, movement, and deepening of the initial Low, are quite complex and suggest dynamic influences.

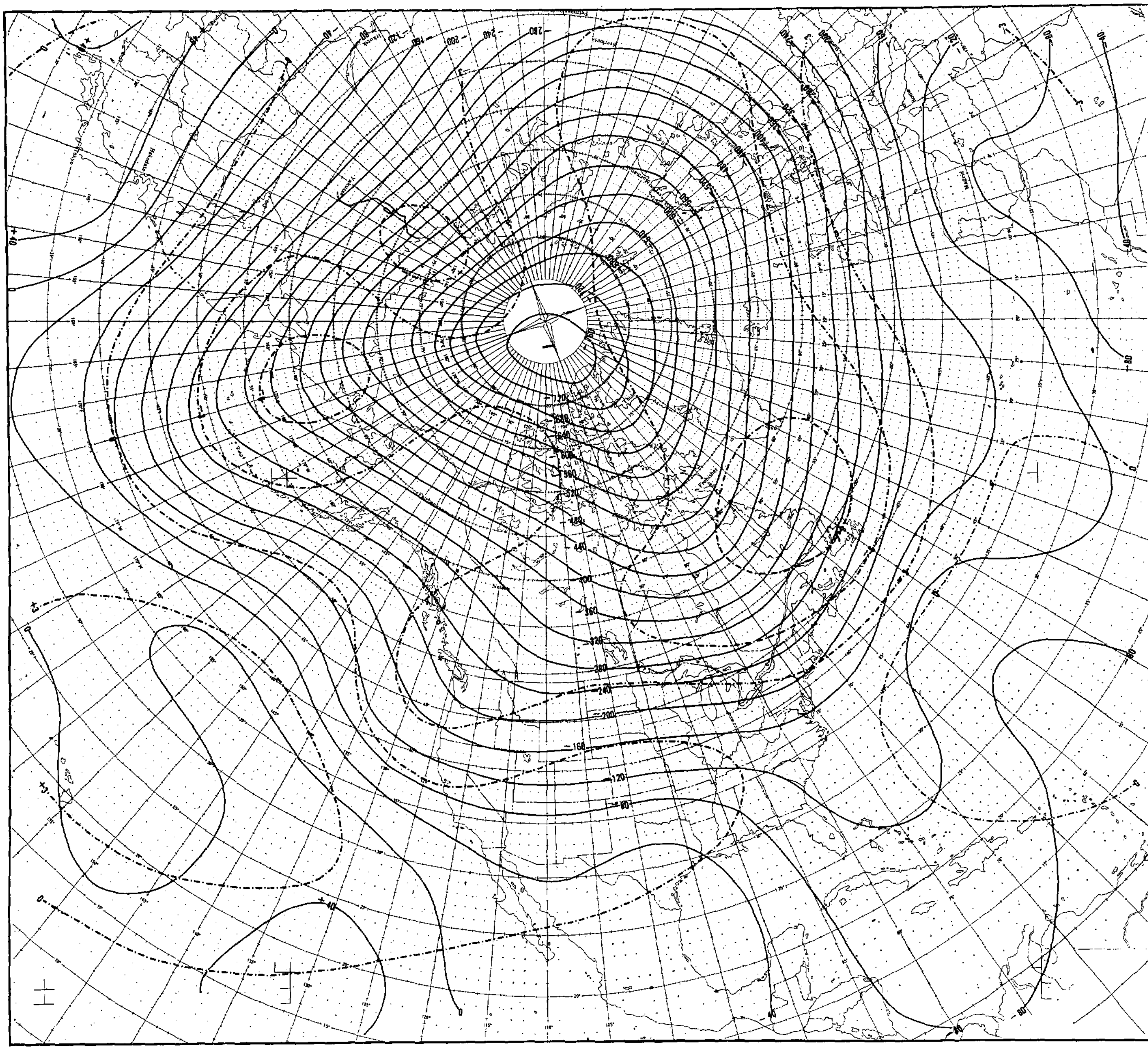

FIGURE 4.—10-mb. height and temperature change chart, September 10, 1958 minus August 15, 1958. Isallohypses and isallotherms as in figure 2.

The autumnal changeover in 1958 was quite similar to that of 1957 with respect to both the timing of the original cyclone formation and the area of occurrence. The first stage of the breakdown occurred over the Alaskan-Siberian region in mid-August of both years and was followed by the initial appearance of the wintertime polar vortex over the same region. However, the frequency with which the inception of the wintertime Low occurs in this region is still unknown.

5. THE ALEUTIAN ANTICYCLONE

One of the better known features of the wintertime mid-stratospheric circulation is the tendency for anticyclogenesis over the Aleutian region. Various authors [1, 2, 5] have discussed the important role that the resulting ridge or anticyclone assumes in connection with large-scale changes in stratospheric circulation and temperature. In 1958 the 10-mb. Aleutian anticyclone appeared in late October (fig. 5). Daily charts drawn for the October 20–25 period show that a sharp trough located over western Alaska at the beginning of the period moved rapidly eastward across the region. An anticyclone, originally located over the western Pacific Ocean, followed behind the trough and intensified rapidly as it moved to a position over southwestern Alaska five days later. Concurrent with the development of the Aleutian anticyclone, the polar Low began a slow movement, leaving its previous position on the Alaskan-

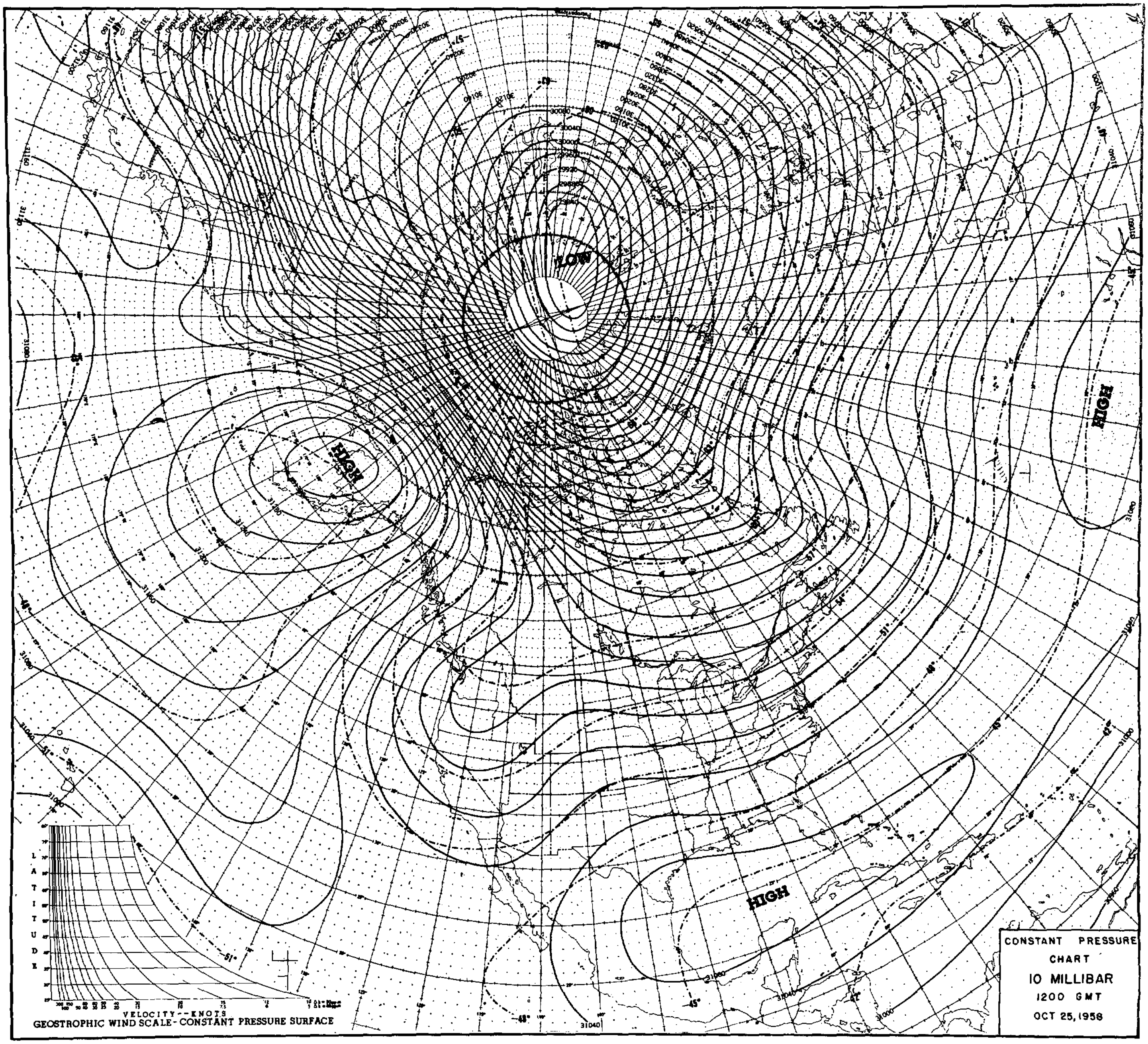

FIGURE 5.—10-mb. chart for 1200 GMT October 25, 1958 (from [10]). Contours and isotherms as in figure 1.

Siberian side of the Pole, and crossed to the European side on October 25. By the end of October, the pronounced increase in isotherm and contour gradients between the anticyclone and the displaced polar Low resulted in a wide jet stream stretching across the Alaskan-Siberian portion of the Arctic southeastward across Canada. Maximum computed geostrophic winds within this jet exceeded 150 kt.

According to Wilson and Godson [11], a stratospheric ridge was a circulation feature over the Alaskan-east-Siberian region in late October of most years between 1949 and 1958. At 10 mb. during the winter of 1957–58 the Aleutian anticyclone made an initial brief appearance in mid-November, then re-appeared in early January to play an important role in a complete breakdown of the stratospheric circulation [7]. On the other hand, during the 1958–59 winter, the anticyclone persisted in the northern latitudes for nearly five months, with its central position ranging from south of the Kamchatka area to central Canada.

6. CIRCULATION CHANGES DURING LATE AUTUMN

Once established, the Aleutian anticyclone began a slow migration eastward. Height rises penetrated completely across Canada while the wintertime cyclonic vortex moved southward on the Eurasian side of the Pole to the Arctic Circle. The climax of the circulation change occurred on November 20 (fig. 6) as the Low

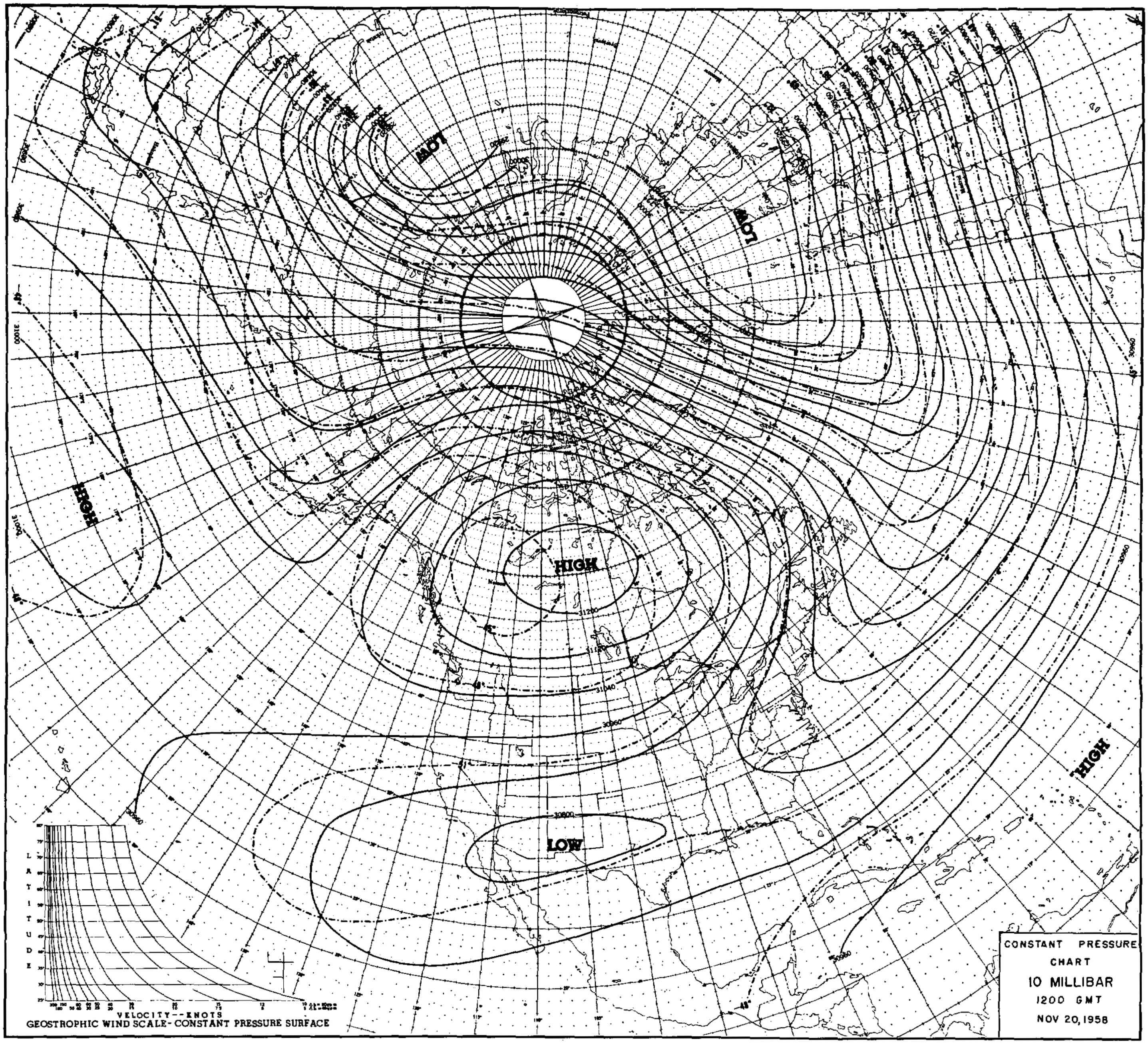

Figure 6.—10-mb. chart for 1200 GMT November 20, 1958 (from [10]). Contour interval 80 m.; isotherm interval 3° C.

appeared to divide into two centers and the anticyclone reached the peak of its eastward penetration across Canada. At that time easterly winds prevailed over the northern two-thirds of the United States and anomalously warm air was located throughout the North American area dominated by the High.

By the end of November, the anticyclone had slowly retreated westward to a position over Alaska. However, a second brief penetration toward the east took place during the first 10 days of December. In this instance, the High divided into two segments, with a stationary system centered over the Pacific Ocean south of the Aleutian area and a migratory center pulsing eastward to a position over northwestern Canada. After the early December penetration the 10-mb. circulation again returned to its typical wintertime configuration, as the deep cyclonic vortex moved back to the polar region and the persistent anticyclone was again located over the Aleutian area.

Positive 10-mb. temperature and height changes in northern latitudes during the November-December period can be seen from the time sections of Thule, Greenland (fig. 7A), and Churchill, Manitoba (fig. 7B). Both sections illustrate the interruption of autumnal cooling resulting from the influx of the warm Aleutian anticyclone, with the two individual pulsations clearly visible. Concurrent with the eastward movement of the Aleutian anticyclone, a major polar trough shifted

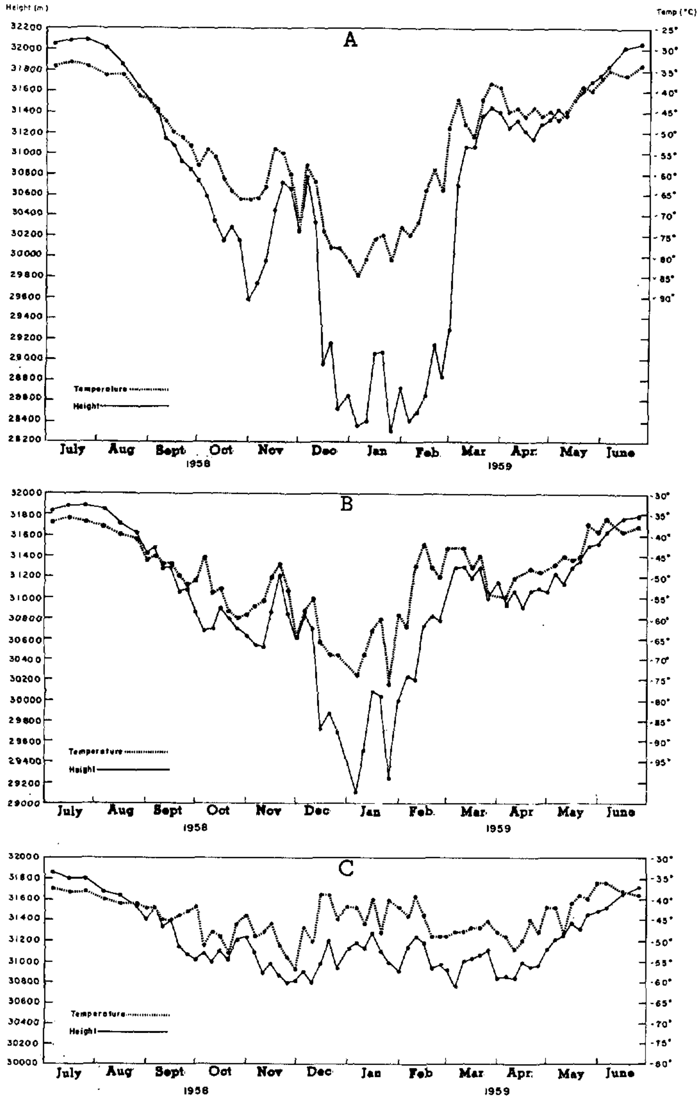

FIGURE 7.—Time sections of 10-mb. height and temperature for (A) Thule, Greenland; (B) Churchill, Manitoba; and (C) Shemya, Alaska. All height and temperature values were interpolated at the station from each chart of [10].

eastward from its preferred position over North America. During the time interval from November 15 to 25, yearly minima of 10-mb. temperature and height were reported over Bermuda, Lajes (Azores), and Bitburg (Germany).

An interesting comparison can be made between the time sections for two stations near the same latitude, but separated by more than a quarter of the hemisphere in longitude. The circulation over Churchill (59° N., 94° W.) during most of the autumn and winter was dominated by the North American polar trough. The temperature curve for this station (fig. 7B) shows a steady decrease, consistent with the deepening of the polar Low, even though it was interrupted at times by pulsations of the Aleutian anticyclone. In contrast, the 10-mb. surface over Shemya (53° N., 174° E.) during the same period was influenced by the Aleutian anticyclone. The minimum temperature for the year was reached at the end of November (fig. 7C) as the warm Aleutian anticyclone moved eastward out of the Aleutian area. Subsequently, temperatures rose rapidly to near summertime levels as the anticyclone shifted westward and was again centered over the area. The annual range of temperatures and heights over Shemya, as interpolated from the year of charts, was only 21° C. and 1,100 m., respectively, as compared to 40° C. and 2,800 m. over Churchill.

7. MID-STRATOSPHERIC EVENTS OF JANUARY 1959

During the beginning of January, a ridge that had been centered over the eastern Caribbean Sea began to intensify and drift northeastward, accompanied by widespread warming. By January 15 (fig. 8) the center of this developing anticyclone, moving at an average speed of about 15 kt., had migrated east-northeastward to a position over Spain. The temperature maximum of −39° C. associated with the anticyclone remained north of its center and appeared to move at about the same rate of speed, even though embedded in a southwesterly flow averaging about 75 kt. As the warm center moved northeastward, temperature rises of nearly 25° C., occurring mainly in the region of maximum height increases, were noted at the 10-mb. level.

While the Atlantic anticyclone was developing and moving east-northeastward, large-scale changes were taking place over western North America. The climax of these changes occurred on about January 15 as the Aleutian anticyclone reached peak seasonal intensity. The height change chart for the 10 days from January 5 to 15 (fig. 9) discloses increases over the northwestern Canadian region in excess of 1600 m., more than double the increases over the Atlantic Ocean. Concurrent with these height increases, the polar Low filled slightly and was displaced from a position near the Pole to a new location over Greenland. The pronounced increase in gradient was accompanied by two fast jet streams with axes located near the centers of maximum height changes. Observed southwesterly winds of 150 kt. were frequent across eastern Canada with one in excess of 200 kt. reported over Keflavik, Iceland. These winds appeared to exceed in speed those composing the northwesterly jet over northern Canada. The intense height rises associated with the Aleutian and Atlantic anticyclones appeared to act as giant pincers causing the polar Low to elongate, and resulted in more meridional flow than at any other time during the winter. This pattern would allow large amounts of comparatively warm tropical air to enter the circulation on the east side of the polar trough, the favored location for "explosive warmings."

From special observations over the Caribbean area during January 1960, Riehl and Higgs [3] described the history of a stratospheric wind shear line. It was suggested that two such shear lines occurred during January 1959. In a later paper, Simpson [4] examined the dynamics of this type of disturbance, and showed an example of one that occurred at the end of January 1959.

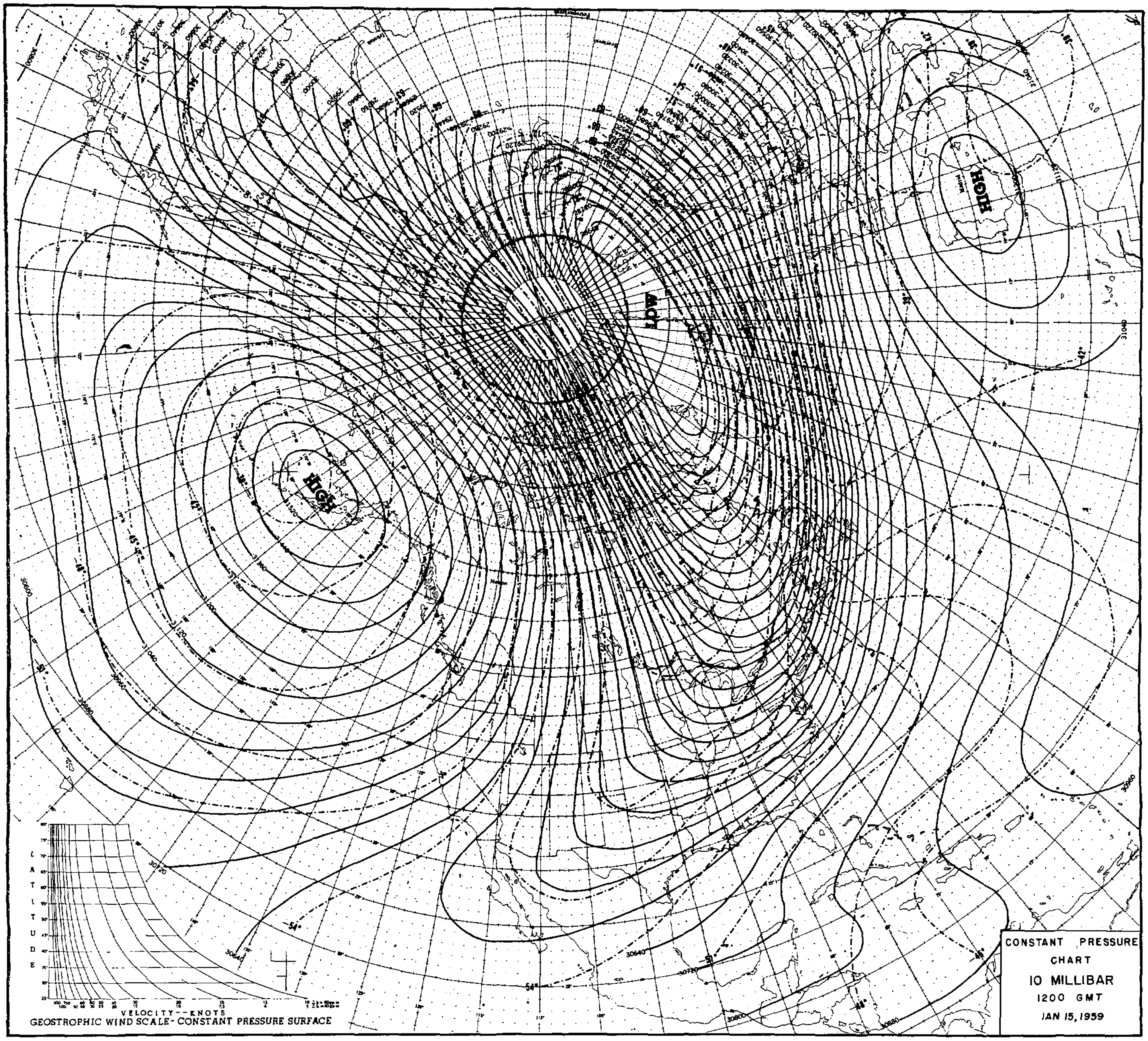

FIGURE 8.—10-mb. chart for 1200 GMT January 15, 1959 (from [10]). Contours and isotherms as in figure 6.

Time sections for Balboa, Canal Zone, plotted for the winter months of 1958–59, disclose considerable variability in the winds above the 15- to 20-mb. layer. However, below this layer persistent easterlies dominated the flow. One of the more abrupt wind changes within this zone of variability took place over the station between January 7 and 9, 1959, (fig. 10), coinciding with the intensification and northeastward movement of the 10-mb. Atlantic anticyclone. In this case it is evident that the magnitude of the wind fluctuation increased with height.

To investigate the possibility of these wind changes being associated with a shear line, sectional streamline charts were analyzed for a period immediately preceding and following January 9 (fig. 11). Although data were sparse, the analyses strongly indicate a disturbance moving northward through the Caribbean region at speeds ranging from 5 to 10 kt. (fig. 11F). The first evidence of this disturbance can be seen on January 9 (fig. 11C) as southwesterly winds appeared over the most southerly stations (Balboa and Curaçao). By January 11 (fig. 11D) the ridge line oriented east-west over Florida had weakened as the trough line moved northward and was situated near 22° N. Two days later the trough line was indistinguishable and appeared to have merged with the large polar trough moving eastward from the continent.

8. THE SPRINGTIME MID-STRATOSPHERIC REVERSAL

Distinct changes appeared in the 10-mb. circulation and temperature fields during the first half of February.

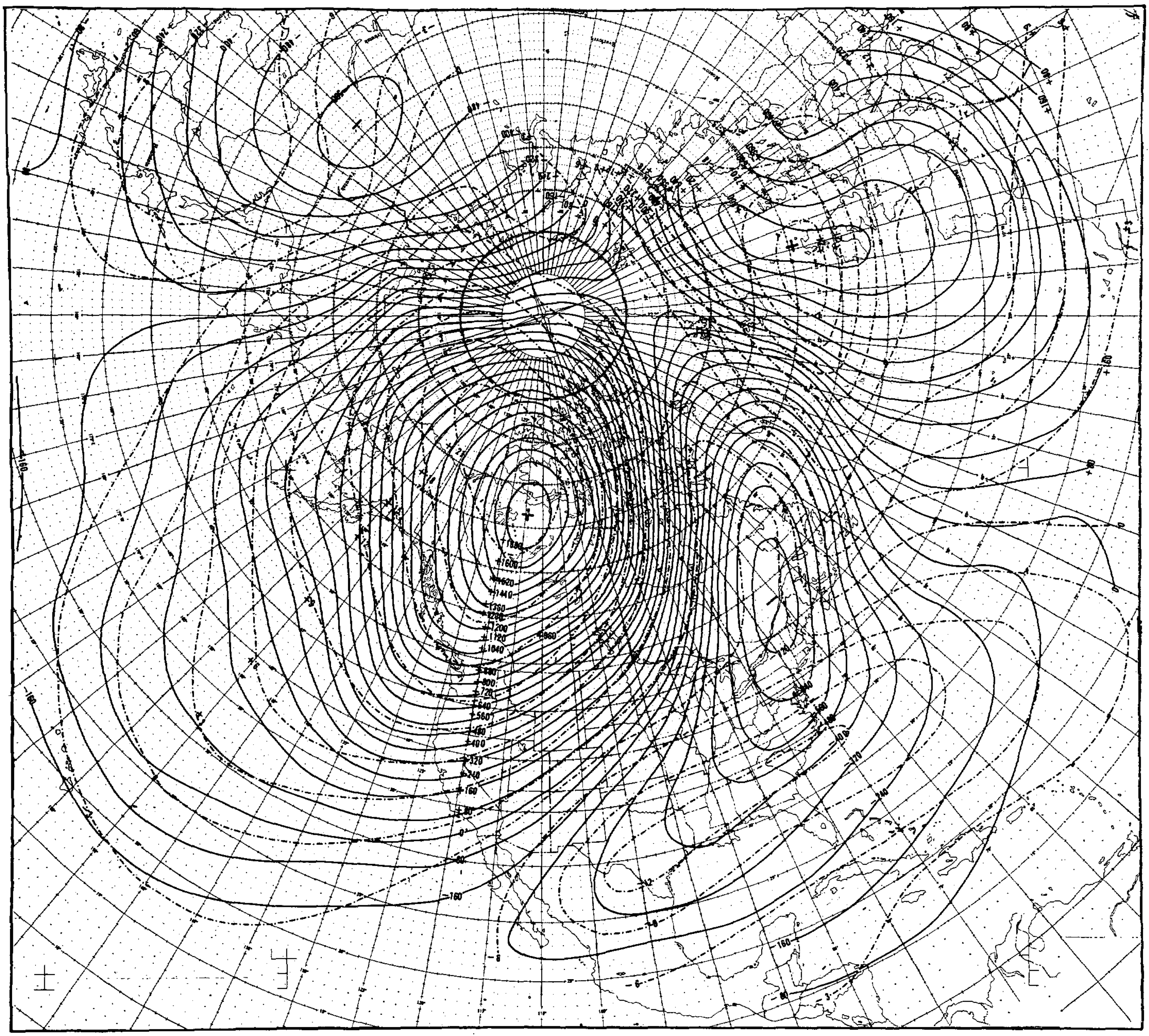

FIGURE 9.—10-mb. height and temperature change chart, January 15, 1959 minus January 5, 1959. Isallohypses at intervals of 80 m., isallotherms (dot-dash lines) at intervals of 3° C.

The most obvious change was the contraction of the polar cyclone over North America, resulting in a marked decrease of wind speed over the lower portion of the continent. At the same time, warm air associated with the Aleutian anticyclone penetrated across Canada. In general, the rather close phase relationship between contours and isotherms, evident throughout most of the winter months, slowly deteriorated as February progressed.

The breakdown of the wintertime circulation commenced actively in mid-February 1959 as the Aleutian anticyclone moved eastward with increasing speed, and perturbations of varying amplitudes began to appear in the height and temperature fields. Temperature measurements over Tripoli, Libya, from February 20 to 25, indicated a strong warming had occurred on the eastern side of a large trough extending southward from the polar Low. Ten days later a weaker warm center was located over the Atlantic Ocean, south of Keflavik, Iceland. Rapid ridging took place along the axis of maximum temperatures, which extended from western Europe, westward through central Canada and into the central Pacific Ocean. On March 10 (fig. 12) maximum heights and temperatures were located over central Canada.

As the Aleutian anticyclone moved eastward to a position over western Canada, the cyclonic vortex shifted southward from the polar region and became centered over Siberia. From mid-March through mid-April the

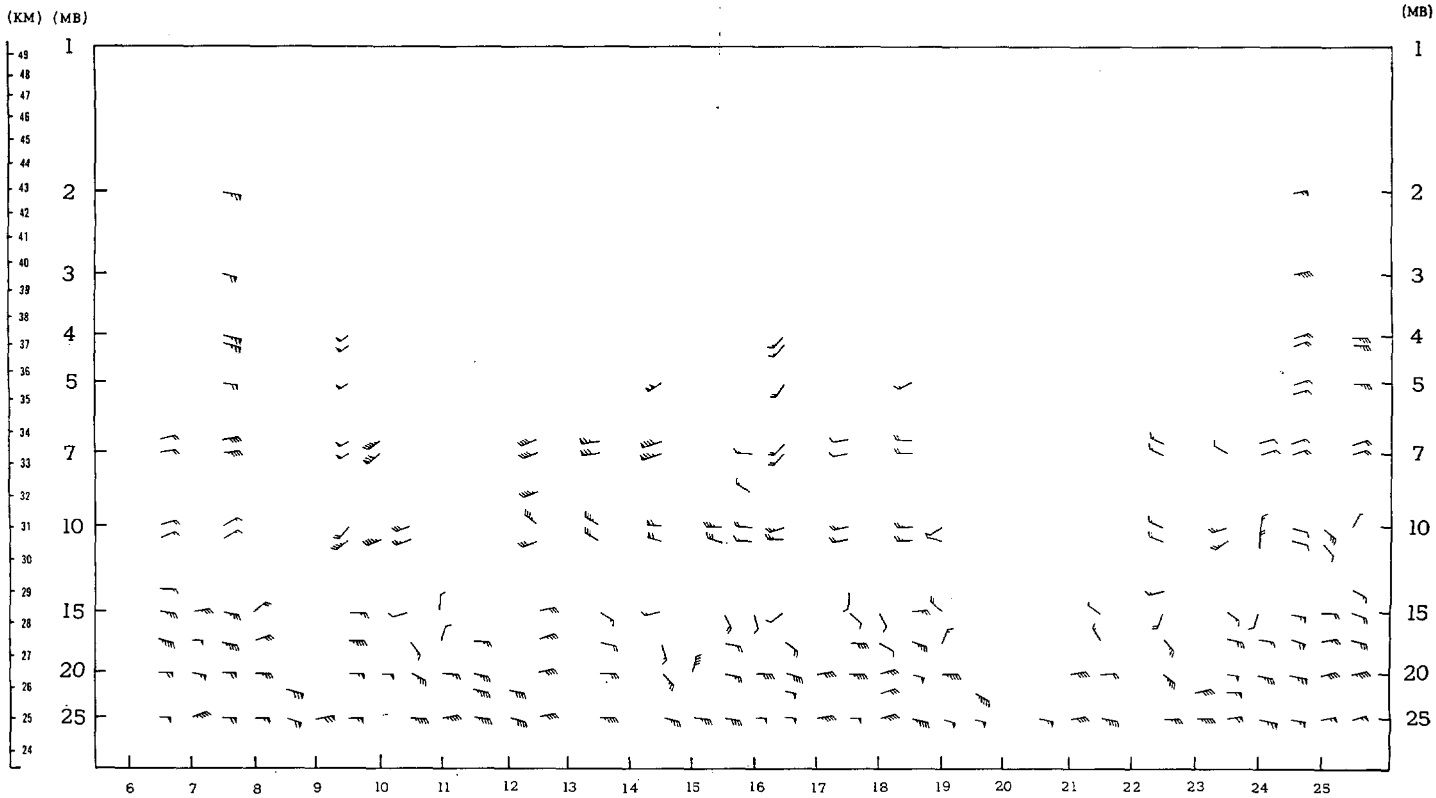

FIGURE 10.—Time section of stratospheric winds for Balboa, Canal Zone, January 6–25, 1959. Wind speed is in knots with one full barb equal to 10 kt., and a pennant equal to 50 kt. Shafts extend toward direction from which the wind is blowing, with north at the top of the diagram and east at the right.

High continued to build and move very slowly northward, while the remnants of the polar cyclone became more disorganized over the eastern half of the hemisphere. Finally, by April 20 the anticyclone settled over the Pole and, except for a brief period in late April, continued to build. A return to easterlies at all latitudes near the end of May completed the cycle of mid-stratospheric events for the year from July 1958 through June 1959.

9. COMPARISON OF 1958 AND 1959 WINTER AND SPRING CIRCULATIONS

A comparison of the circulation and temperature patterns from late January through May of 1959 with those of the same period of 1958 shows pronounced dissimilarities. In late January 1958 an "explosive warming" and complete breakdown of mid-stratospheric circulation transpired as the Aleutian anticyclone moved northeastward, thence northward, and was centered near the Pole on February 1. The intense polar vortex divided into two weaker cold vortices, one located over Europe and the other over the Gulf of Alaska. The breakdown was followed by the return to the polar region of a considerably weakened cyclonic vortex in early March. The transition to summer conditions was gradual, beginning in late March with the arrival of solar insolation to northern latitudes. Not until the middle of May, when the center of the summertime High settled over the polar region, was the reversal complete (See [7] and [8] for further details). This was in sharp contrast to the dominance of the cold polar cyclone throughout January and most of February 1959. The warming and circulation change began in late February and culminated with the summertime anticyclone making its appearance over the Pole in mid-April. Thus, the reversal took place a full month earlier than in 1958.

The differences between the two years are vividly shown by a comparison of polar temperatures (fig. 13). At the conclusion of the strong midwinter warming during 1958, temperatures over the Pole decreased to almost −70° C. The slow, radiational warming trend that followed resulted in summertime conditions by the middle of May. However, in 1959, temperatures lower than −70° C. persisted throughout January and most of February followed by a moderate warming period during late February and early March and again in the last half of March. Polar temperatures thereafter generally remained higher than −45° C.

The late February 1959 amplification of the Aleutian anticyclone and its migration eastward in March closely

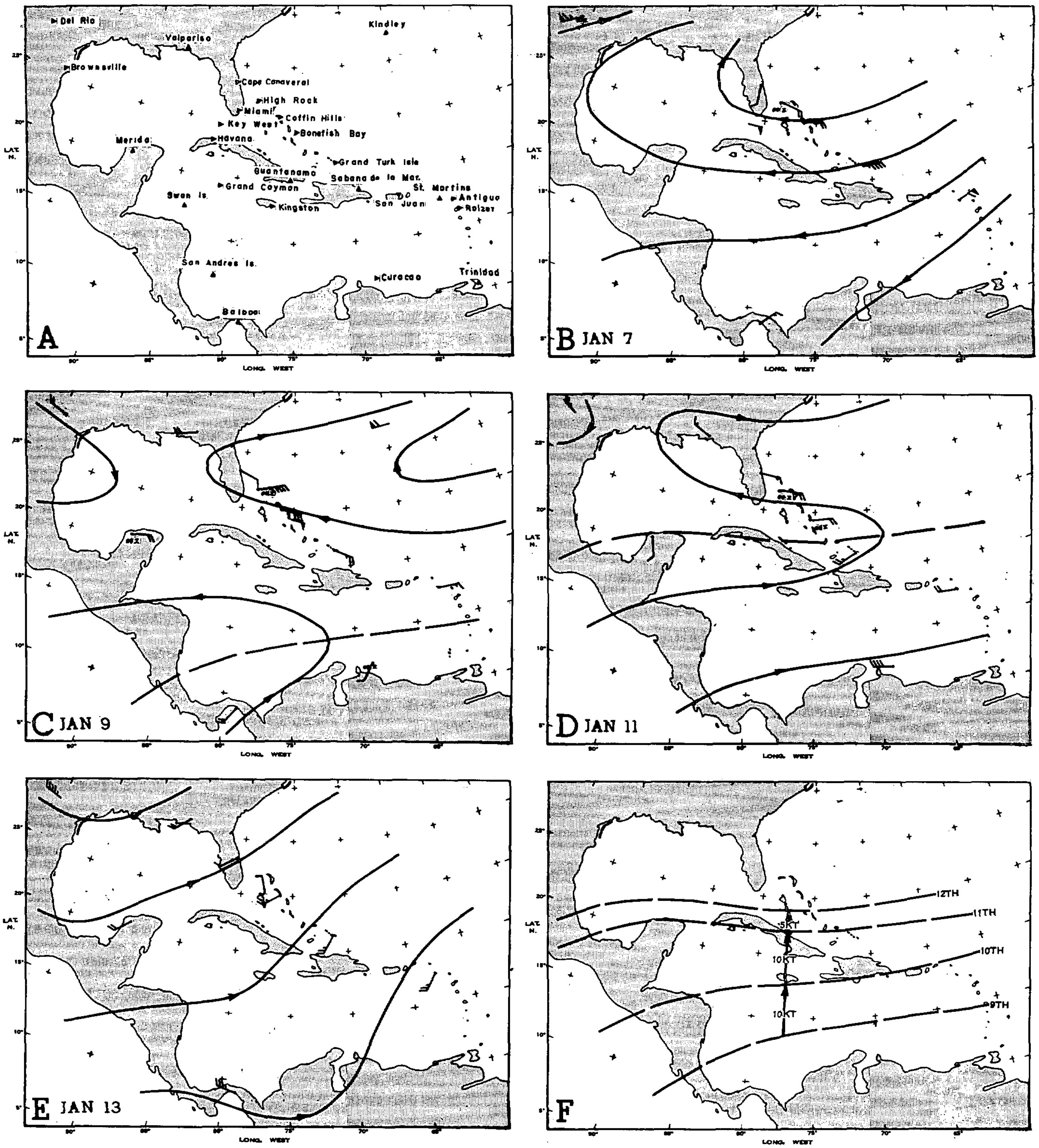

FIGURE 11.—(A) Network of upper air stations in the Caribbean area. (B), (C), (D), (E) Streamline analysis of 10-mb. surface. Wind speeds are in knots; winds marked 00Z are those 12 hours previous to map time. (F) Daily 1200 GMT position of equatorial shearline January 9–12, 1959 and rates of mean 24-hr. displacement.

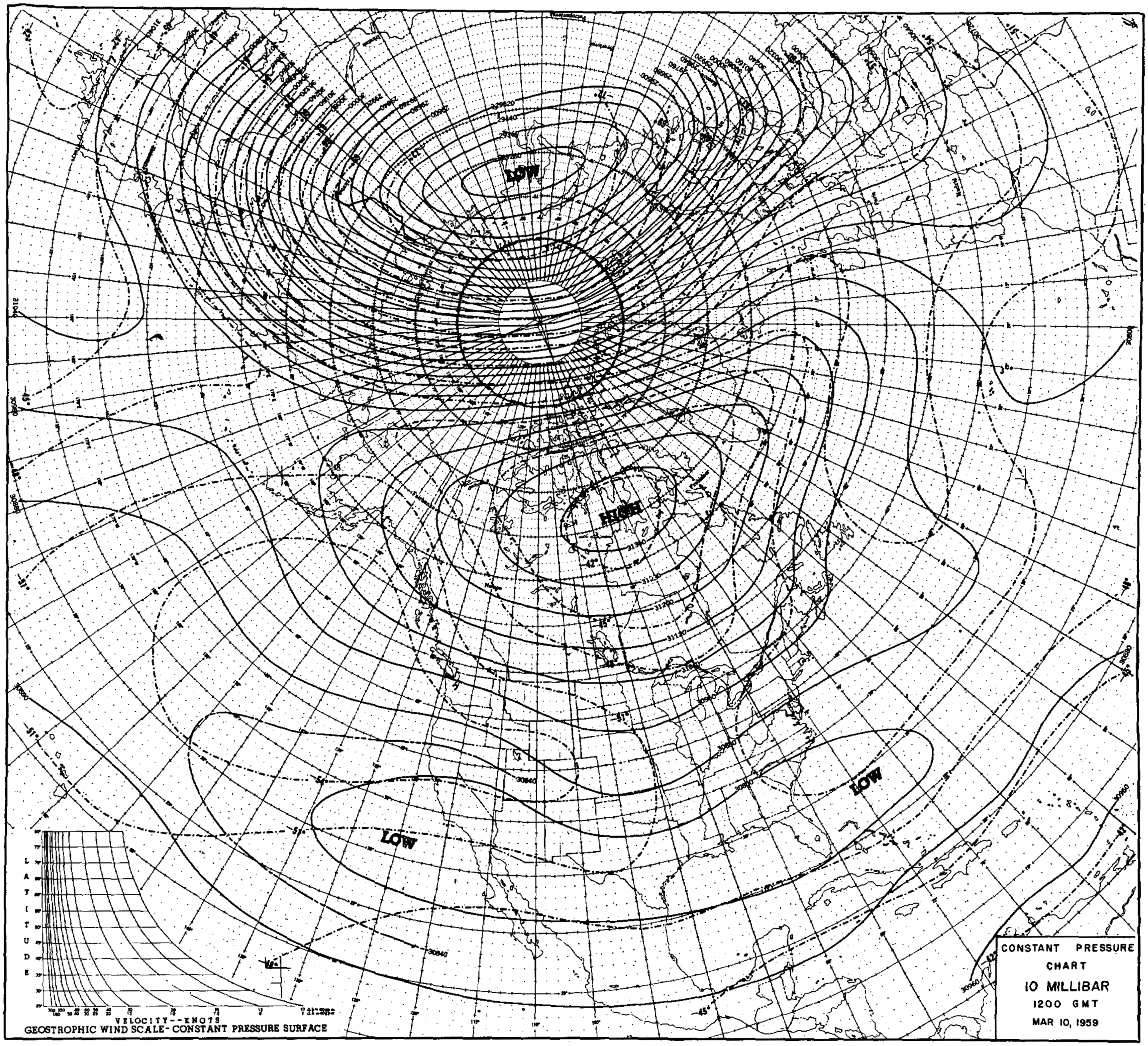

FIGURE 12.—10-mb. chart for 1200 GMT March 10, 1959, (from [10]). Contour interval 80 m.; isotherm interval 3° C.

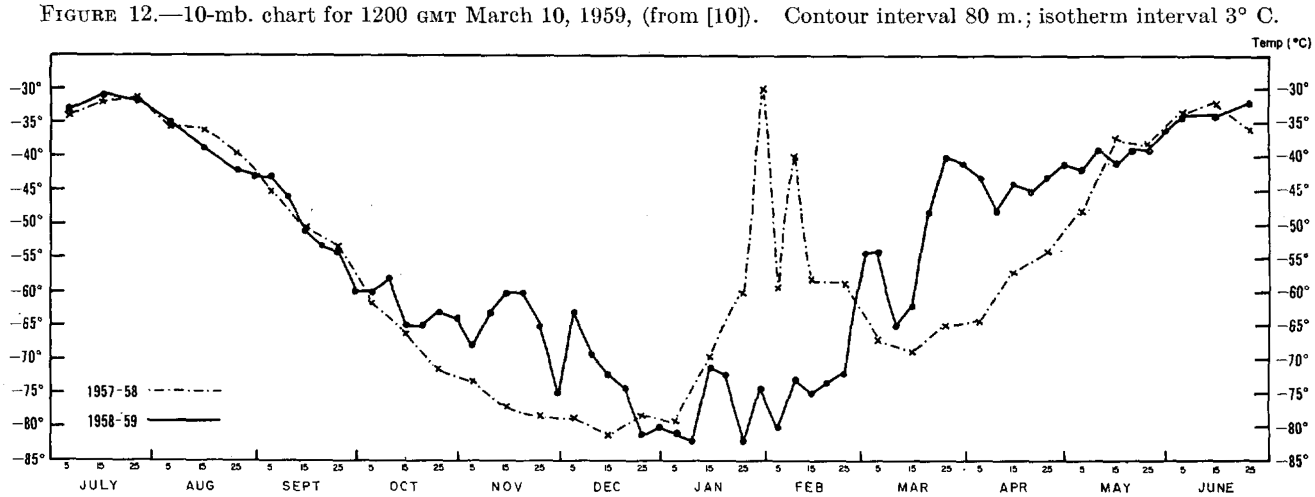

FIGURE 13.—Comparison of 10-mb. North Pole temperatures during 1957–58 (from [8]) to those extrapolated from charts analyzed for 1958–59 (from [10]).

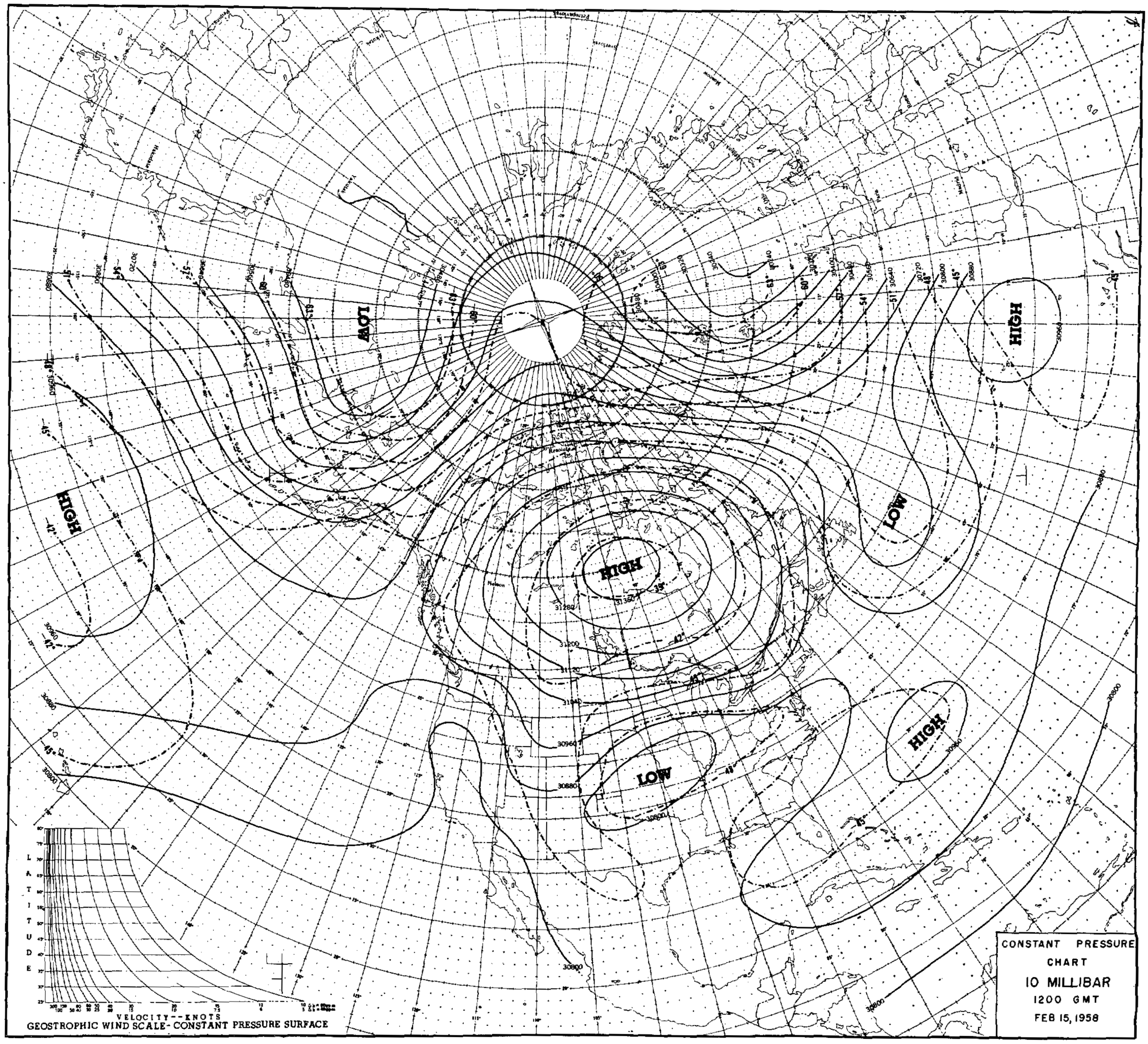

FIGURE 14.—10-mb. chart for 1200 GMT February 15, 1958, (from [9]). Contour interval 80 m.; isotherm interval 3° C.

paralleled the sequence of events during January and February of the previous year. The February 15, 1958 (fig. 14) and March 10, 1959 (fig. 12) charts show the pattern that existed in both years. A comparison of these charts reveals the similarity of major features that existed to this point. However, instead of the return to a cold cyclonic vortex in the polar region, such as occurred in the previous year, the cyclone during 1959 remained displaced to the Eurasian side of the Pole and the anticyclone maintained its intensity and position in the high latitudes. As a consequence of the relatively high temperatures and heights near the polar region, and the rapidly increasing solar radiation over northern latitudes, the 1959 summertime transition was completed a full month earlier than that in 1958.

10. CONCLUSION AND SUMMATION

Even though many of the analysis problems have been alleviated and data coverage has increased, interpretation of mid-stratospheric data from July 1958 through June 1959 remains relatively subjective when compared with tropospheric and lower stratospheric analysis methods. Throughout the analysis procedures, a special effort was made to preserve continuity in the movement of small-amplitude perturbations. However, in many cases this proved impossible due to large areas with sparse data and the doubtful accuracy of some observations.

The analyses confirm earlier statements concerning the extreme stability of the summertime mid-stratospheric circulation. There is strong evidence that small perturbations are embedded in the easterly flow, with minimum amplitudes during the peak of the season. Isotherm patterns associated with these perturbations are extremely difficult to delineate, since errors in reported temperatures may be as large as one-half of the entire summertime pole-to-equator temperature differences.

When compared with those of the previous year, the charts illustrate how radically different wintertime circulation patterns may be. The strength and movement of the Aleutian anticyclone, which is so intimately related to wintertime circulations and circulation changes, may well be employed as an indicator of events during this season. Charts for 1959 disclose considerable wintertime activity, over low latitudes, around the periphery of the polar vortex. However, only the Caribbean area stations approximate a network suitable for analysis of these relatively small-scale systems. An indication of the frequency of occurrence and preferred regions of disturbances, such as shear lines, awaits a longer series of charts and greater data coverage over low latitudes.

ACKNOWLEDGMENTS

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